Appendix H
Classification of Structures

H-1. General

Critical structures, per ER 1110-2-1806, are those which are part of a high hazard project and whose failure will result in loss of life. Loss of life can result directly due to flooding, or indirectly from secondary effects. Structure classification is to be based on a total project evaluation which considers all project features, their interdependence, and the impact substandard performance of one project feature might have on the importance and criticality of other project features. A critical structure determination involves consideration of the possibility of failure, and the potential for loss of life should failure occur. Under certain circumstances the population in the vicinity of the failed structure may not be at risk, or if at risk, there may be sufficient warning time to evacuate the people from downstream areas that will be inundated. Various earthquake, flood, and latent deficiency failure condition scenarios must be examined to determine if failure can result in loss of life. Critical structures are subject to more stringent sliding safety factor requirements. The types of hydraulic structures which could be classified as critical include gravity dams and spillways, arch dams, urban flood walls, coastal flood walls, and intake towers. Structures not qualifying as critical structures shall be classified as normal.

H-2. Classification Process for Critical Structures

a. Project characteristics. Various project characteristics should be investigated to determine how they may affect project performance during major flood and earthquake events. The characteristic of the impoundment area, and of the downstream reaches of the project are especially important to safety. For flood control projects, it is likely that conditions conducive to landslides, subsidence, and erosion will be most critical during extreme flood events when the impoundment is at its highest stage and project discharge is at a maximum. Site geology and seismicity are important when evaluating earthquake ground motions, sliding stability, liquefaction, and earthquake induced fault displacements. The quantity of water impounded by the project, distance to populated areas, and the number of people at risk are important when evaluating life safety performance. Project characteristics to be considered during the safety evaluation include:

b. Failure scenarios. All potential structure failure scenarios must be investigated to determine their impact on structure performance. Erosion and piping can adversely affect structure stability and structure performance. When structures are located in areas of high seismicity, earthquake effects must be considered in the failure scenario investigation. Earthquake effects include ground motion demands, fault displacements, subsidence, slope instability, and liquefaction.

c. Failure consequences. Structures which fail to meet performance objectives can result in loss of life, or damage to property, essential lifelines or the environment. Loss of life is the only consequence applicable to the structure classification process. In general, project performance objectives are to:

- Retain and release impoundments in a planned regulated manner.
- Prevent structure damage under usual and unusual load conditions.
- Prevent structure collapse under extreme load conditions.
- Allow adequate time under emergency conditions to evacuate people from areas subject to flooding.
- Remain operational to permit a controlled release of impounded water following major flood and earthquake events.

d. Structure classification. The consequences of potential failure will determine whether a structure is to be designated as *critical*, or *normal*. The *critical* structure designation is only to be used in those cases where failure of the structure to perform will directly or indirectly lead to loss of life. Where the lives of people are not at risk, or when there is time to evacuate people from locations where they would be a risk should failure occur, the structure shall be classified as *normal*.

H-3 Examples of Classifications.

a. Gravity dam - flood control project.

(1) Project characteristics. The project consists of a straight axis gravity dam and ungated overflow spillway. The dam has no permanent reservoir. The purpose of the dam is to protect against flooding resulting from winter storms and thunderstorm runoff. The dam is designed to detain flood flows, and to release stored water in a regulated manner so as not to cause property damage and loss of life. The dam has the capacity to store 1,500,000 cubic meters (1,260 acre feet) of water. A sudden release of stored water could result in loss of life. The canyon upstream of the dam has steep side slopes and sparse vegetation. The dam reservoir can be filled to capacity in a matter of one or two hours following a major thunderstorm. The canyon downstream of the dam is also steep and narrow and extends to the edge of populated areas. The dam is located two miles upstream of a town that has a population of 23,000. Approximately 5,000 people live in the area that would be inundated should the dam fail. It can be expected that most, if not all, of those people would be at risk.

(2) Failure scenarios.

(a) Latent deficiencies. Since there is no opportunity to fill the reservoir under controlled conditions to monitor displacements and uplift pressures, the dam is considered potentially susceptible to failures caused by unknown latent deficiencies, deficiencies that may not be discovered until flooding occurs. The warning time will be short since the reservoir will fill rapidly under thunderstorm runoff conditions.

(b) Earthquakes. The dam is located in an area where major earthquakes are possible. However, the dam is dry 95-percent of the time so that dam failure and loss of life due to an earthquake related failure is highly improbable.

(c) Floods. The potential for a flood type failure exists for extreme conditions where the water overtops the dam and the discharge is of sufficient magnitude and duration such that erosion of dam foundation material occurs. Warning times for this type of failure should be sufficiently long to evacuate people from the downstream area that would be inundated. Failures due to excessive uplift and piping are possible failure scenarios for which warning times would be short and not sufficient to evacuate people from the downstream area that would be inundated. These type of failure mechanisms, although extremely unlikely, should be considered since there will be no opportunity to evaluate dam performance under controlled pool raise conditions.

(3) Structure classification. Monitoring the reservoir and performance of the structure under controlled conditions is not an option. Sudden failure and release of impounded water, although extremely unlikely, is possible. Warning times under such circumstances will not be sufficient to evacuate people from the downstream areas that would be inundated. The dam is considered to be a *critical* structure, and therefore the safety provisions applicable to *critical* structures must be used for all flood loading conditions. The safety provisions applicable to *normal* structures may be used for earthquake loading conditions since failure due to earthquake ground motions will not lead to loss of life.

b. Gravity dam - hydropower project.

(1) Project characteristics. The project consists of gravity dam monoliths (non-overflow sections), generator bay monoliths, and gated spillway monoliths. The project routinely impounds water to within 2 feet of the top of spillway gates to maximize power benefits. Flood storage benefits are small because the capacity to store flood flows is limited and because there are few people living in areas subject to flooding. The project has the capacity to store 0.50 cubic kilometers (400,000 acre-feet) of water. Water routinely impounded for hydropower is equal to 0.43 cubic kilometers (350,000 acre-feet). When flooding is forecast the reservoir is lowered. Storage up to 0.12 cubic kilometers (100,000 acre-feet) can be provided for flood protection. The canyon upstream and downstream of the dam has steep side slopes and sparse vegetation. All populated areas in the vicinity of the project are located above the canyon rim and therefore not subjected to flooding. The downstream canyon widens out about 45

kilometers (28 miles) from the dam. The nearest town that would be prone to flooding is located 50 kilometers (31 miles) downstream of the project. Should the dam fail there would be approximately 10 hours to notify and evacuate people from the area that will be inundated. Approximately 100,000 people live in the town located 50 kilometers (31 miles) downstream of the project. . It can be expected that approximately 2000 of the people would be at risk due to flood innundation.

(2) Failure scenarios.

(a) Latent deficiencies. The reservoir is kept within two meters (6.5 feet) of the top of dam. The hydrostatic loads that are routinely applied to the dam are 95-percent of those estimated for extreme flood events. Therefore the possibility that there are unknown latent deficiencies that could lead to erosion, slope instability, subsidence, piping, and other conditions that might impair safety is extremely remote.

(b) Earthquakes. The dam is located in an area of low seismic activity. Earthquake loadings will not control the design.

(c) Floods. The potential for a flood type failure is extremely unlikely. The spillway is sufficient to pass the probable maximum flood (PMF). The stilling basin is designed to accommodate heavy discharge conditions and is inspected on a regular basis. Failures due to excessive uplift and piping are unlikely failure scenarios since the project is routinely subjected to high heads, and since periodic inspections and monitoring of project instrumentation will catch excessive uplift and piping conditions well before such conditions can lead to failure.

(3) Structure classification. Regardless of failure scenario, warning times would be sufficient to evacuate people from downstream areas that would be inundated. The dam is considered to be a *normal* structure and all safety requirements will be those applicable to *normal* structures.

c. Urban flood wall.

(1) Project characteristics. The project consists a 4-meter (13 foot) high concrete I-wall that is part of a 10-km (6-mile) levee system providing flood protection to an urban area. The project is located adjacent to a major river which has exceeded flood stage on many occasions. The wall and river bank are subject to erosion during flood stage since neither have riprap protection. The project has the capacity to prevent 600,000 cubic meters (500 acre-feet) of water from inundating populated areas. The unprotected side of the levee-flood wall project consists of a river basin and agricultural farm land. The protected side is a densely populated urban area. The urban area is immediately adjacent to the levee-flood wall project. Approximately 20,000 people reside in the area that would be inundated if the flood wall should fail.

(2) Failure scenarios.

(a) Latent deficiencies. Erosion of the river bank and levee can occur during flood events. This erosion can lead to failure of the wall during intermediate river stages (when overtopping of the wall will not occur).

(b) Earthquakes. Earthquake failure is unlikely. If the wall failed due to earthquake ground motions there would be no loss of life.

(c) Floods. There is a potential for the wall and levee to be overtopped during an extreme flood event. However, under these conditions there is sufficient time to warn and evacuate people residing in flood prone areas. Overtopping can lead to local wall and levee failures.

(3) Structure classification. The flood wall is considered a *critical* structure since the wall could fail suddenly without warning during intermediate flood stage conditions. Therefore the safety provisions applicable to *critical* structures must be used for flood loading conditions. Since failure due to earthquake ground motions will not lead to loss of life, the safety provisions applicable to *normal* structures may be used for the earthquake loading conditions.

d. Intake tower.

(1) Project characteristics. The intake tower is part of a flood control project that consists of a 85-meter high earth-and-rockfill embankment dam, a side channel regulated spillway, outlet works, and intake tower access bridge. The intake tower is founded on rock, is 80-meters (260 feet) high, and rectangular in shape. Flow regulation through the intake tower - outlet works is accomplished with two slide gates located at the upstream end of the outlet works tunnel. Although used primarily for flood control, the pool for most of the year is maintained at a level that submerges 40-meters (130 feet) of the tower. The pool of record resulted in 60-meters of tower submergence. Maintenance bulkheads are provided in the intake tower to allow the tunnel, outlet works structures, and slide gates to be inspected and maintained. The maintenance bulkheads must be placed under balanced head. The outlet works tunnel is 5 meters (16 feet) in diameter and located in the rock abutment for the dam. The time required to drawdown the pool, in case it should be necessary to make repairs to the embankment dam, is very long (approximately 2-months). Under maximum pool conditions the dam impounds 0.11 cubic kilometers (90,000 acre-feet). Under recreational pool conditions the dam impounds 0.07 cubic kilometers (60,000 acre-feet). The intake tower is surrounded by water and therefore always under balanced head conditions. Both the upstream and downstream river channels are steep and heavily wooded. Urban populated areas exist within 10 km (6 miles) downstream of the dam. If water were suddenly released from the project the flood wave would reach populated areas in 45 minutes. This not considered to be adequate time to evacuate people even under ideal conditions. Should dam failure occur, the lives if 100,000 people would be at risk.

(2) Failure scenarios.

(a) Latent deficiencies.. The intake tower is surrounded by water and therefore always under balanced head conditions. The potential for latent deficiency failure mechanisms developing during flood events is extremely small. It is highly unlikely that during major or extreme flood events debris from landslides in the upper basin would block tower intakes and reduce discharge capability. The spillway has the capacity to pass PMF flows without the additional discharge capacity provided by the outlet works. Overtopping of the dam is not possible, even under conditions where the tower intakes are blocked by debris.

(b) Earthquakes. The project is located in a high seismic area. There is a 50% chance that severe damage, and possibly collapse of the tower and access bridge could occur during a major earthquake.

- *Tower collapse.* Since the tower is operated from a remote location there will be no direct loss of life due to tower collapse, nor will collapse of the tower cause loss of life due to a sudden release of pool. Should tower collapse and the outlet works tunnel exposed to ungated operation, the flow released downstream under open channel flow conditions will be insufficient to cause erosion that could lead to dam failure.

- *Dam failure due to impaired tower drawdown capability.* Earthquake ground motions resulting from major or extreme earthquake events will weaken the dam resulting in subsequent failure due to seepage and piping of impervious core material. Pool drawdown through the outlet works (even when the outlet works is discharging at full capacity) will not occur at a rate sufficient to prevent dam failure

- *Dam failure due to outlet tunnel failure and the inability to make an upstream closure.* Under certain damage scenarios it is possible that water escaping the outlet works tunnel could lead to embankment dam erosion and failure. This could occur if the tower were damaged severely enough to prevent an upstream closure, and if the outlet works tunnel, due to fault displacements was damaged severely enough to allow water to escape onto the dam embankment. Since the outlet works tunnel is located in a rock abutment and since potential water transmission paths will not lead to embankment dam erosion, this failure scenario is extremely unlikely.

(c) Floods. The intake tower is surrounded by water and therefore always under balanced head conditions. The potential for tower failure during extreme flood events is extremely small.

(3) Structure classification. The various failure scenarios investigated suggest that loss of life due to intake tower failure is extremely unlikely, and that the tower is not critical with respect to overall project performance. The intake tower is therefore classified as a *normal* structure.

e. Navigation lock - upstream gate monolith.

(1) Project description. The project consists of a 33.5 m (110 foot) wide by 206 m (675 feet) long navigation lock with the capability to accommodate an 25 m (82 feet) lift. The lock is founded on a shale formation which is known to have clay seams with low shear strength. The reservoir upstream of the lock and dam impounds up to 0.62 cubic kilometers (500,000 acre) feet of water. The basins upstream and downstream of the project consist of steep hillsides with marginally stable slopes. Landslides have occurred when hillsides are saturated by rainfall. The navigation lock is located in an urban setting. The hillsides upstream and downstream of the project have been developed for residential and commercial use. Subsidence and landslides are possible under rapid drawdown conditions that could result from a sudden loss of pool. Approximately 15,000 people are at risk.

(2) Failure scenarios.

(a) Latent deficiencies. Unexpected movements along a deep seated clay seam layer could lead to failure of the gate monolith and loss of pool. This could occur during normal operation with the lock chamber at tailwater (maximum differential head during normal operation). Failure could also occur when the lock chamber is unwatered for maintenance (maximum differential head condition). Failure could be sudden without warning, and without time to fill the lock chamber to equalize the differential head.

(b)Earthquakes. The project is located in a low seismic area. Failure of the gate monolith due to earthquake ground motion is extremely unlikely.

(c)Floods. The project spillway has the capacity to pass the inflow of major floods without overtopping the project structures. Flood induced failure is extremely unlikely.

(3) Structure classification. Since there is a high probability that failure of the gate monolith will indirectly cause loss of life, the gate monolith is considered a *critical* structure. Sliding factor of safety requirements for *critical* structures therefore will be used for *normal operating*, and *maintenance* load conditions.